

Assessment of Air Traffic Controller Acceptability of Aircrew Route Change Requests

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Abstract— NASA developed the traffic aware strategic aircrew requests concept for a cockpit automation that identifies route improvements and advises the aircrew to request the change from the air traffic controller. In order to increase the chance of air traffic control approval, the automation ensures that the route is clear of known traffic, weather, and airspace restrictions. Hence the technology is anticipated to provide benefits in areas such as flight efficiency, flight schedule compliance, passenger comfort, and pilot and controller workload. In support of a field trial of a prototype of the technology, observations were conducted at the Atlanta and Jacksonville air traffic control centers to identify the main factors that affect the acceptability of aircrew requests by air traffic controllers. Observers shadowed air traffic controllers as the test flight pilot made pre-scripted requests to invoke acceptability issues and then they interviewed voluntarily fifty controllers with experience ranging from one to thirty-five years. The most common reason for rejecting requests is conflicting with traffic followed by violating air traffic procedures, increasing sector workload, and conflicting with major arrival and departure flows and flow restrictions. Quantitative parameters such as the distance that a route should maintain from sector boundaries and special use airspace were identified and recommended for inclusion in the automation.

Keywords: *TASAR; TAP; Aircrew requests, Flight Optimization; Field Trial;*

I. INTRODUCTION

The Traffic Aware Strategic Aircrew Requests (TASAR) is an on-board automation concept intended to identify trajectory improvement opportunities clear of known traffic, weather, and airspace restrictions prior to the aircrew initiating a trajectory-change request to Air Traffic Control (ATC) [1]-[4]. The cockpit tool being developed to meet the objectives of the TASAR concept is called the Traffic Aware Planner (TAP). The technology is anticipated to increase ATC approval frequency and thereby provide benefits in areas such as flight efficiency, flight schedule compliance, passenger comfort, and pilot and controller workload [5]. In addition, NASA intends to use TASAR to help accelerate the adoption of Automatic

Dependent Surveillance-Broadcast (ADS-B) equipage by the aircraft operator community.

The TASAR project aims to develop an onboard, traffic-aware, flight-optimization capability for near-term, low-cost implementation by airlines and other airspace users [4]. Previously, many activities were conducted to that end, including assessing benefits [5], safety/hazards [6], low-cost certification/approval [7], and human factors, culminating with Flight Trial 1 (FT-1) in November 2013 [8]. FT-1 validated the TAP software application in flight with live avionics data feeds and allowed for operational use by airline pilots in a live ATC environment. It confirmed that TAP is capable of performing its intended functions in this environment, taking a significant step in establishing its readiness for airline implementation [8]-[9]. NASA has established formal partnerships with Alaska Airlines and Virgin America for TASAR operational-use testing onboard revenue flights during 2016 and beyond.

One objective of the second flight trial (FT-2) was to identify key factors that impact the air traffic controller acceptance of pilot requests to change their trajectories while in flight [10]. Accounting for these identified factors in TAP's advisories would make them more acceptable to controllers. Other research has investigated operational acceptability of route changes. Evans and Lee developed a predictor of operational acceptability for reroute advisories, applying data mining techniques to flight plan amendment data and data on requested reroutes collected from a field trial of NASA's Dynamic Weather Routes tool [11]. Factors included historical usage of the advised route, location of the maneuver start point, reroute deviation, and demand levels in the maneuver start sector. Taylor and Wanke considered in their reroute optimization many factors that reflect operational acceptability including conformance of the reroute to historically flown routes, sector congestion, and required point-outs and inter-facility coordination [12]. Some trajectory requests are always unacceptable to controllers, such as ones that violate the separation requirement with another aircraft or are incompatible with an ATC procedure. Other requests'

acceptance depends on certain characteristics of the request and of the environment at the time of the request. FT-2 focused on gaining insights on two types of factors: (1) The request interaction with airspace structure such as sector boundaries and special use airspace (SUA), and (2) the request complexity such as the number of waypoints and maneuvers. FT-2 also investigated external factors such as workload. The ATC acceptability assessment approach is described in the next section. Then the analysis results are described in two sections: general statistical insights and quantitative acceptability factor characterization. Finally, recommendations are made for incorporating the results in the automation.

II. ASSESSMENT APPROACH

Observation and elicitation of controller acceptability of pilot requests were performed during the flight test. The observations were conducted at two en-route facilities, Atlanta (ZTL), from June 8 to June 16 2015, and Jacksonville (ZJX), from June 17 to June 20 2015, and included two components:

- (1) Observation of air traffic controllers as they handled the flight test aircraft that flew anonymously in their airspace. The observers monitored the pilot-controller communications as the pilot made scripted trajectory change requests designed to test hypothesized factors.
- (2) Observation of pilot-controller communications in sectors without the test aircraft travelling through their airspace. The observers then elicited acceptability factors from the controllers through follow up interview and questionnaire.

A. Acceptability Factors

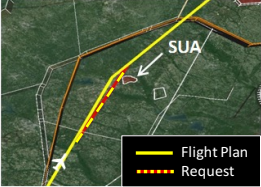

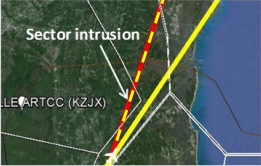



A list of hypothesized acceptability factors was generated and confirmed during preparatory visits to ZJX and ZTL. Two sets of factors were considered: Controlled factors that were varied directly through scripted requests and environment factors that were varied indirectly. Eight controlled factors representing airspace structure interactions and maneuver complexity levels are described in Table 1. The acceptability of the factors in Table 1 depends on environment factors, four of which are: the controller who handles the request, traffic density, traffic flow type (arrival, departure, or en route), and workload. It is important to attain a variation in these uncontrolled factors such that they do not mask the effects of the controlled factors. Therefore, these factors were varied indirectly by flying at different times such that requests were made from different controllers and during different traffic patterns and densities. Each day included a morning flight that was alternated between 9 and 10 AM and an afternoon flight that was alternated between 1 and 2 PM.

B. Scenarios and Experimental Matrix

Scenarios were designed for each request to invoke the factors in Table 1. Some scenarios invoked more than one factor and hence provided observations on multiple factors. The scenarios were scripted to cover, to the extent possible, all possible requests from every area of the ZTL and ZJX airspace. This ensured the availability of scenarios to attempt even if the

flight deviated from the nominal filed flight plan. Since there was no communication between the ground observers and the onboard team during the flight, the scenarios were collected in a booklet that was used by the ground observers and the TAP engineer onboard, who was in charge of planning and timing the requests. The scenarios were ordered by the ground observers before each flight and communicated to the TAP engineer onboard such that the two teams were coordinated at the start of each flight. In order to induce the geometry intended by the underlying factor, for example to fly close to a boundary between two sectors or to make a request closely before or after a handoff, specific instructions were given along with the scenario, including:

Table 1 Acceptability factors (solid yellow is original route, dashed is requested route)

1. SUA: Fly close to an active SUA 	2. Sector boundaries: Fly along sector boundaries 
3. Sector intrusion: Cross in and out of sectors 	4. Handoff: Request during handoff between sectors 
5. Multiple centers: cross from center to another 	6. Multiple waypoints: include multiple waypoint 
7. Multiple maneuvers: Includes altitude and lateral maneuvers	8. Fix type: Request to use fixes in low altitude (E class) and high altitude

- The criteria to identify if the scenario was applicable,
- The details of the request to be made by the test pilots,
- The geometric location along the nominal route to execute the scenario, and
- The frequency of the sector where to make the request.

A total of twelve flights (six flight pairs) were available for observation: Two flight pairs to KMG, two to KBHM, and two to KTPA. Three requests per flight were assumed available for observation: two scripted and manually made and one generated by TAP. During the test, some flights made fewer

than three requests and some flights made up to four requests. Some factors that were concluded quickly as non-important were de-emphasized, such as the class of the fix used in a request (factor 8 in Table 1). Off nominal conditions, such as weather, were not included in the pre-designed scenarios because they may not materialize during the test. On two days of the observations in ZTL significant weather impacted the test flight and scenarios were designed in real time to interact with the weather. In ZJX requests were devoted mostly to attempt to interact with active SUAs since ZTL did not have sufficient SUA activity and interacting with SUA in ZJX was challenging due to lack of activity during the test.

C. Metrics and Data Collection

The main data source for identifying and characterizing controller acceptability of pilot requests was the interviews with the controllers. Fifty controllers volunteered to be interviewed, thirty-five in ZTL and fifteen in ZJX. The observers collected the data with the help of pre-designed data collection sheets. Four types of information were collected from each interviewed controller: (1) demographic information (2) general request acceptability statistics and factors (3) information regarding observed events, mostly events related to the scripted scenarios and (4) information regarding the hypothesized acceptability factors. Each of these types of information and their collection method/sheet is described below in this section. The analysis is given in the next section.

1) Demographic Information

Figure 1 shows the age distribution of the fifty interviewed controllers at ZTL and ZJX. The age ranged between twenty-nine years and fifty-five years, with a mean of forty two years.

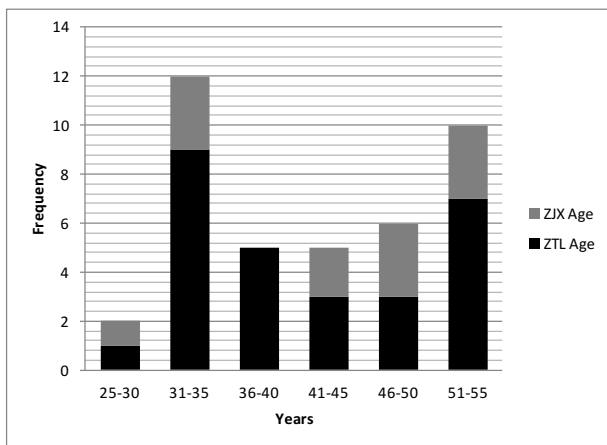


Figure 1 Controller age distribution.

Figure 2 shows the experience distribution of the fifty interviewed controllers at ZTL and ZJX. The experience ranged between two and thirty-two years, with a mean of seventeen years.

2) General Statistics

Figure 3 shows an excerpt of the general questions that each controller was asked. The analysis of the answers to each question is discussed in the next section.

3) Event-related Information

When observing a sector, the observers used the observation collection sheet shown in Figure 4 for observed pilot request events. The information collected included: the aircraft call sign, the sector observed, the trajectory change request, the number of aircraft in the sector, the workload level as estimated by the controller or the observer, the type of traffic (arrival, departure or en route) at the time, the result of the request (accepted or rejected), the reason for rejection, and descriptions of the event including pictorial depictions.

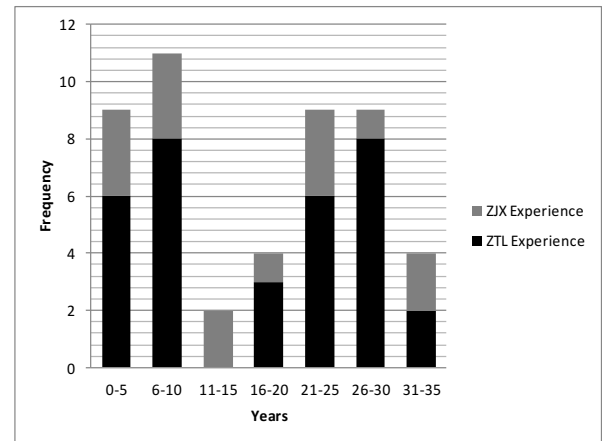


Figure 2 Controller experience distribution.

Interview questions

- What percentage of pilots makes requests for trajectory change? 20%
- What is the most common type of trajectory change requested? short cut
- What is the next most common type of trajectory change requested? altitude
- What factors do you consider when evaluating a request? (1) traffic
(2) workload
(3) do I have control (handoff)
(4) proximity to airport destination.
- What percentage of trajectory change requests do you reject? 20%
- What reasons or factors make you reject trajectory change requests? (1) traffic (2) workload [frequency congestion]
(3) Wx.
- What is the most common reason for which you reject trajectory change request? traffic.

Figure 3 General interview questions.

Thirty-six requests were made during the flight test. Seven according to TAP advisories while the others according to scripted scenarios. One request was related to a weather event that was not scripted beforehand and was planned during the test. Eight requests were rejected. Nine were accepted with a delay because the controller conducted needed coordination or resolved any traffic implications due to the request.

8. What constitutes high, moderate, and low workload? Give an example of each situation

High workload	Moderate workload	Low workload
Wx + ≥ 5 o/c.	15 o/c w/o night wx	< 10 no wx.

Figure 7 Workload assessment example.

III. GENERAL ACCEPTABILITY STATISTICS

Statistics that resulted from the generic questions of Figure 3 are presented in this section, followed in the next section by statistics related to the characteristic parameters of the hypothesized acceptability factors of Table 1.

Controllers were asked what the most and next most common types of trajectory change requests pilots make. Figure 8 shows the frequency of the answers. The short cut request is the most common; it was mentioned by thirty nine controllers as the most common request and by eight controllers as the next most common request. It is followed by altitude change request, which was listed as the most common request by nine controllers but as the next most common by twenty nine controllers. Finally weather deviation requests were mentioned by one controller as the most common type and by twelve controllers as the next most common request. The dominance of these factors was the same in ZTL and ZJX and hence they are not differentiated in Figure 8.

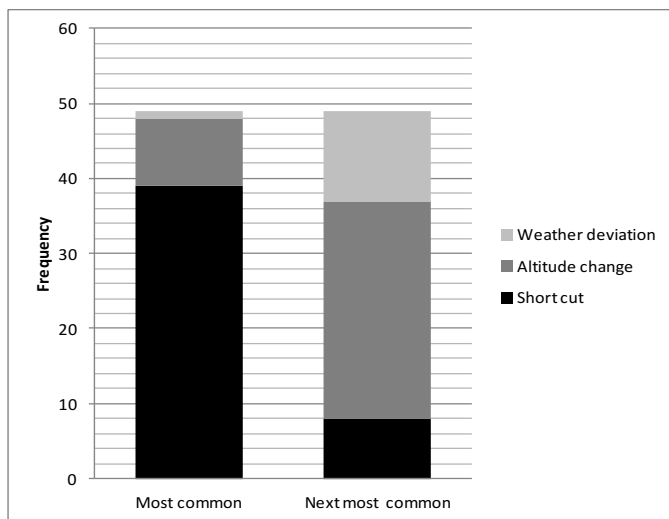


Figure 8 Most common pilot trajectory change requests.

Figure 9 shows the frequency of the main factors that the controllers mentioned they consider when evaluating a pilot request for trajectory change. The factors are ordered on the horizontal axis by their overall frequency. Each factor's frequency is divided into its occurrences as first, second, third or fourth mentioned factor. While the controllers were not asked to rank the factors by importance, the order in which they mentioned the factors was assumed to carry such implication.

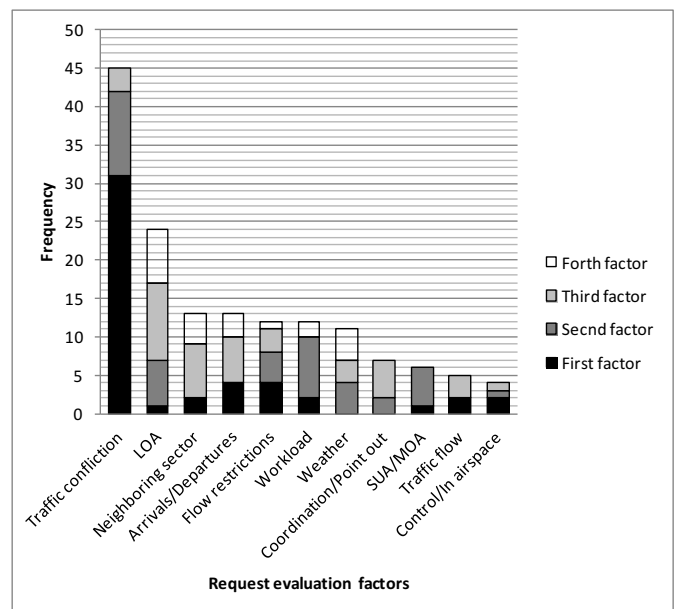


Figure 9 Factors for controller evaluation of pilot requests.

Traffic conflict was mentioned most frequently by controllers as the first factor they consider when evaluating pilot requests for trajectory change. It should be noted that the questions were subjective and that no effort was made to define each term that a controller mentioned objectively across controllers due to the time constraint of the interview. Therefore, traffic conflict may represent to one controller a larger set of events than to another controller. As an example, traffic flow appeared as a factor with low frequency; however, for some controllers it may have been assumed under traffic conflict. Arrivals/departures was the third most mentioned factor; it was often associated with streams of the major airports Atlanta and Charlotte. Flying opposite to a busy arrival flow may have been mentioned as arrivals/departures conflict by one controller but assumed as part of traffic conflict by another controller. The same can be said about workload, which may encompass many of the other factors and about flow restrictions, which may include letters of agreement (LOA) constraints in addition to traffic management initiatives. Therefore, the ranking should be taken as subjective.

Figure 10 shows a frequency plot of the rate at which controllers reject pilot requests for trajectory change. Most controllers mentioned that they reject less than ten percent of the pilot requests and all answers were below fifty percent. Both ZTL and ZJX controllers attempt to accommodate pilots and grant the requests unless there is a very good reason not to. For example, requests cannot be granted if they violate ATC procedures such as LOAs. Agreements between facilities and between adjacent controllers are important even if they are not written in ATC procedures. For example, most controllers mentioned that they would not accept a request that causes high workload and coordination activities for other controllers. In ZJX few controllers mentioned that they would go as far as asking a Military Operations Area (MOA) if they can accept a point out to allow an aircraft to travel across or close to its boundary.

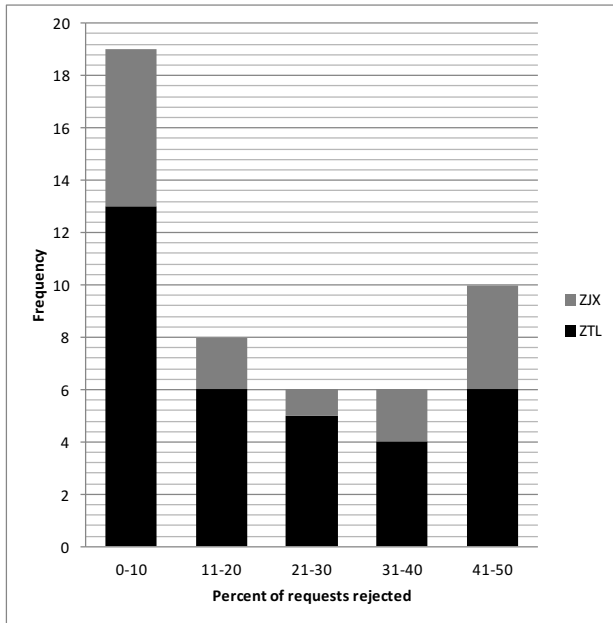


Figure 10 Percentage of pilot requests that are rejected by controllers.

IV. FACTOR CHARACTERISTICS

Statistics and insights from the data collected about each of the acceptability factors of Table 1 are described in this section.

A. Request to Fly Close to Active SUA

Controllers were asked how close to an active SUA a trajectory change request can be to be acceptable under different workload levels. They were asked to give lower and upper limits if possible. The acceptable distance from an active SUA ranged between a minimum of zero under low workload and a maximum of ten nautical miles under high workload. The majority of controllers answered that they would accept requests that are at the legal minimum distance of three nautical miles under low workload but they require five nautical miles under high workload. The increasing trend of the mean acceptable distance from an active SUA with the workload level can be seen in Figure 11. It increases from a range of 3.2-3.5 at low workload to a range of 4.3-4.5 nautical miles at high workload. The standard deviation (presented as error bars) also increased with the workload. Figure 12 shows the frequency of the controller answers, taken as the mean between the lower and upper limit values, in bins of two nautical miles and categorized by the workload level. Clearly larger acceptable distances from an active SUA are mentioned more frequently under high workload.

B. Request to Fly along Sector Boundaries

Controllers were asked how close to the boundary between two sectors can a requested trajectory travel in order to be acceptable. The main issue with flying close to the boundary between sectors is the necessity of a point out. If an aircraft flies closer than 2.5 nautical miles from the sector boundaries, the controller in charge of the aircraft has to call the controller

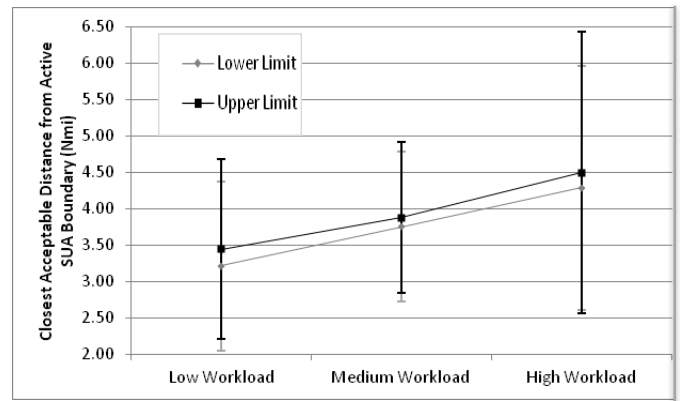


Figure 11 Acceptable mean distance from active SUA.

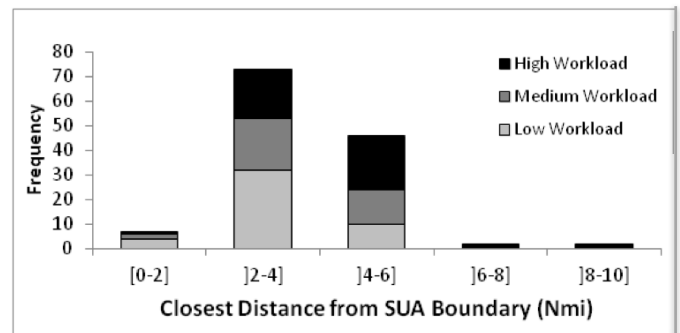


Figure 12 Distribution of closest acceptable distance from active SUA.

of the adjacent sector to have him/her monitor the aircraft as well. This procedure is known as point out and causes an increase in workload for both controllers. Although it is very common for controllers to point aircraft out, under high workload, particularly of the adjacent controller, they can decide to either reject a request that needs a point out or delay it in order to create enough separation from the sector boundary and avoid the need for the point out.

This behavior was reflected in the controller answers. Figure 13 shows an upward trend of the mean distance from sector boundaries required by controllers with workload. The mean acceptable distance increases from half nautical mile at

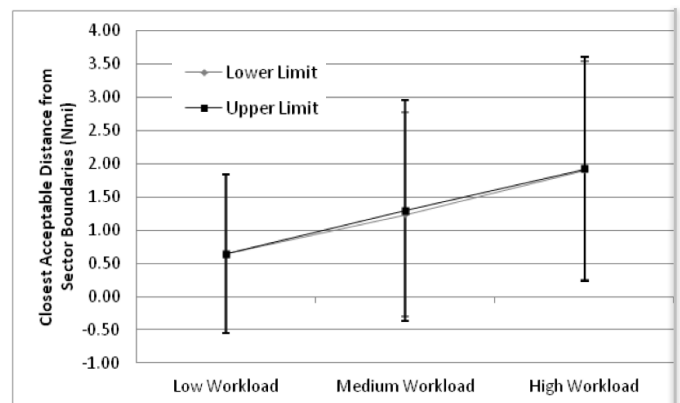


Figure 13 Acceptable mean distance to fly parallel to sector boundaries.

low workload to 1.9 nautical miles at high workload. This indicates that the controllers would increasingly reject requests that create point out situations as workload increases. Most controllers did not distinguish between lower and upper limits for each workload level and provided only one value making the range between the lower and upper limits almost invisible. A similar trend is observed in the distribution of the data shown in Figure 14 where higher acceptable distances from sector boundaries (of four to six miles) are mentioned more frequently under high workload. However, most controllers, in all workload situations, would accept a request that has the aircraft flying less than 2.5 nautical miles from the boundaries.

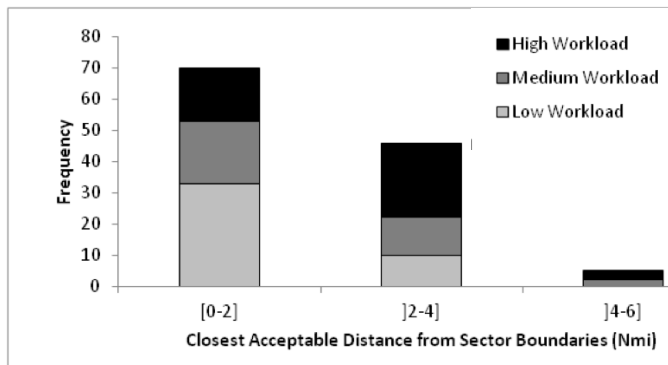


Figure 14 Distribution of acceptable distance from sector boundaries.

C. Request Causing Sector Intrusion

Controllers were asked if they would accept requests that intrude briefly into a sector (clip a sector) and, if not, how far they would want a request to be to avoid clipping. Clipping a sector causes a point out to the clipped sector similarly to the previous factor (flying along sector boundaries) adding workload to the controllers of both sectors. To avoid the point out, as explained for the previous factor, controllers would have to keep the aircraft more than 2.5 nautical miles away from the adjacent sector's boundaries.

An upward trend of the mean distance required by controllers and its standard deviation (presented as error bars) with workload is visible in Figure 15. The mean acceptable distance increases from almost zero at low workload to about

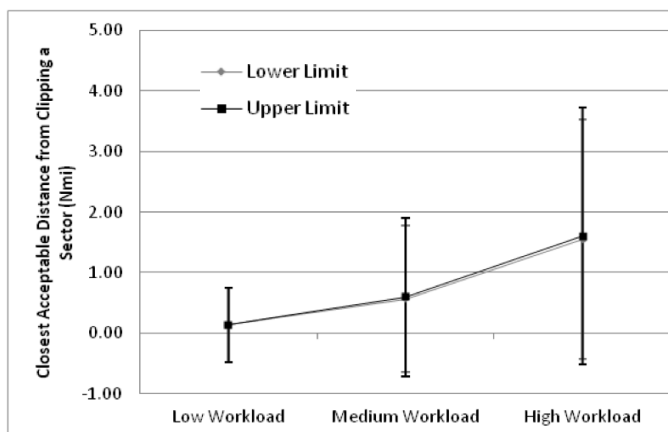


Figure 15 Mean acceptable distance from sector clipping.

1.6 nautical miles at high workload. Most controllers provided only one value making the range between the lower and upper limits almost invisible. A similar trend is observed in the distribution of the data shown in Figure 16 where higher acceptable distances from sector clipping are mentioned more frequently under high workload. The acceptable distance ranged between zero under low workload and nine nautical miles under high workload. Similar to the previous factor, most controllers answered that they would accept requests that clip sector boundaries even under high workload.

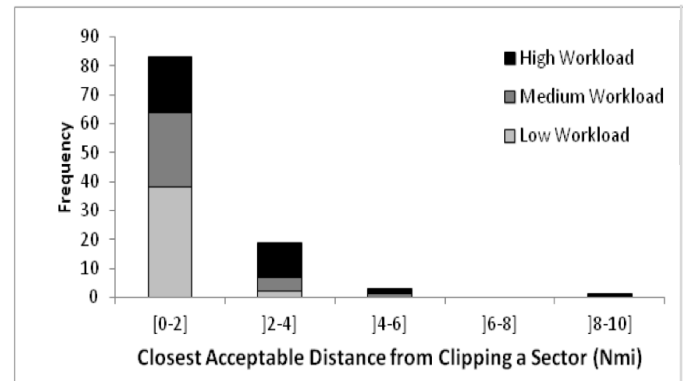


Figure 16 Distribution of acceptable distance from sector clipping.

D. Time of Request Before Handoff to Another Sector

Controllers were asked how close to the handoff to the next sector they would still accept a request before telling the pilot to make the request to the next sector. Controllers are required to handoff an aircraft to the next sector when the aircraft is still in their airspace. The system automatically flashes the aircraft when it is closer than three nautical miles from the next sector boundary. When the controller of the next sector accepts the handoff, he/she assumes control of the aircraft but may not be talking to the pilot until communication is transferred. During this time, it frequently happens that a pilot makes a request to a controller who is not in control of the aircraft anymore, because pilots have no awareness of the sector boundaries. In this case, the controller has to call the controller of the next sector and ask to hand the aircraft back to her/him. The coordination requires additional workload. During the observations, multiple requests occurred close to the handoff status. Depending on the workload, controllers either asked to make the request to the next sector or called back and accommodated the request.

An upward trend in the mean acceptable time before handoff to another sector with the workload level can be seen in Figure 17. The mean increased from a range of 2.4-2.8 minutes under low workload to a range of 3.7-4 minutes under high workload. The results are supported by the distribution of the data shown in Figure 18, where longer times before handoff were required by the controllers under higher workload. The acceptable time before handoff ranged between zero under low workload and ten minutes under high workload. Indicated by the mode in Figure 18, most controllers answered that they would accept a request up until two minutes from handoff under low workload. The mode of the acceptable request time before handoff rose to five minutes under high workload.

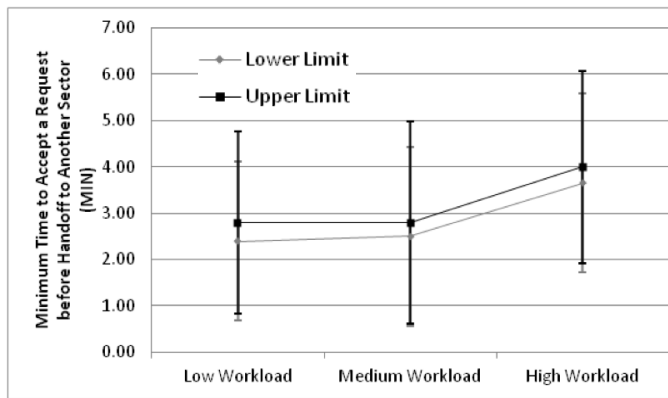


Figure 17 Acceptable request time before handoff to another sector.

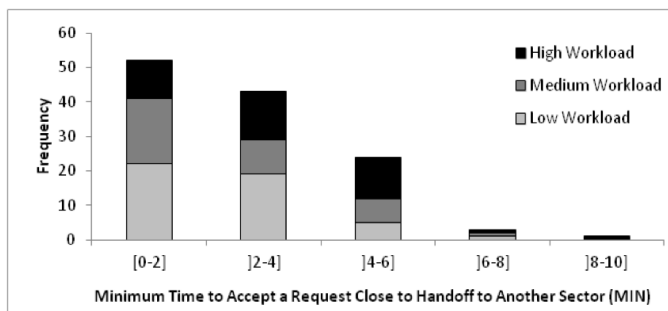


Figure 18 Distribution of minimum acceptable request time before handoff to another sector.

E. Time of Request Before Handoff to Center

Controllers were asked how close to the handoff to another center they would still accept a request before telling the pilot to make the request to the next center. Controllers repeatedly stated that, while historically the handoff to another center had been more problematic, with the En Route Automation Modernization (ERAM) the handoff to another center is as simple as the handoff to another sector inside their own center. Hence most of the answers were similar in these two situations as can be seen in Figures 19 and 20, with a slight shift in the mode of the acceptable request time before handoff to 3-4 minutes in Figure 20.

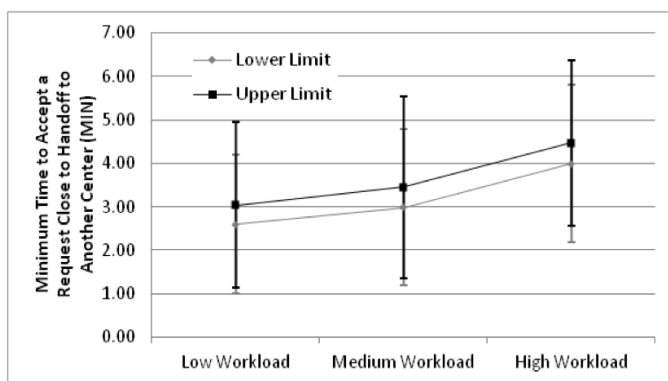


Figure 19 Acceptable request time before handoff to another center.

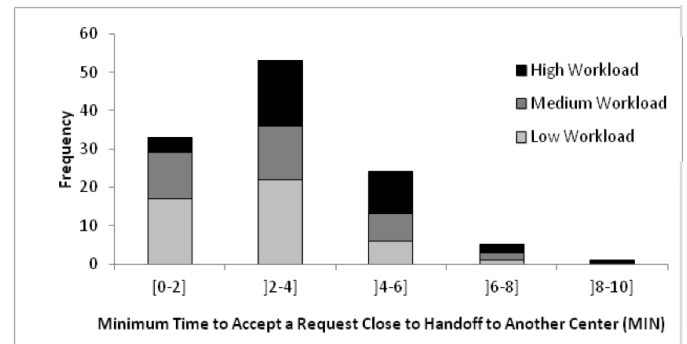


Figure 20 Distribution of minimum acceptable request time before handoff to another center.

F. Time of Request After Handoff from Another Sector

Controllers were asked how soon after receiving handoff from another sector they accept a pilot request. The acceptable time after handoff ranged between zero under low workload and two minutes under high workload conditions. There is no clear trend in the mean with workload as can be seen in Figure 21. The distribution shown in Figure 22 shows that most controllers preferred knowing a request immediately after the handoff even under high workload. They explained that this helps them in planning for the request. If the requesting aircraft is not in his/her airspace yet, the controller can delay the response. If the request is urgent, for example for weather deviation, the controller can request from the controller of the previous sector control of maneuvering the aircraft. Then he/she accommodates the request with added workload.

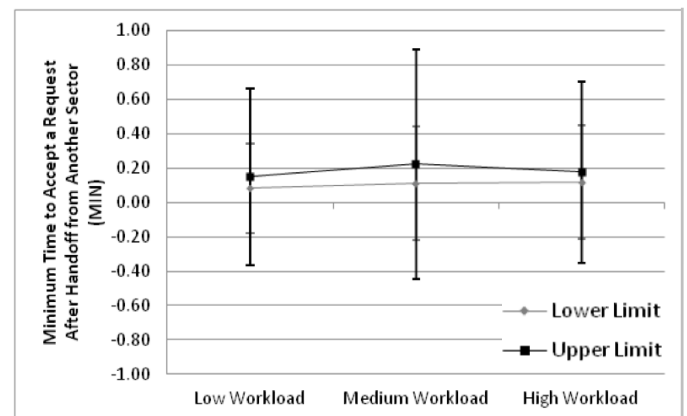


Figure 21 Acceptable request time after handoff from another sector.

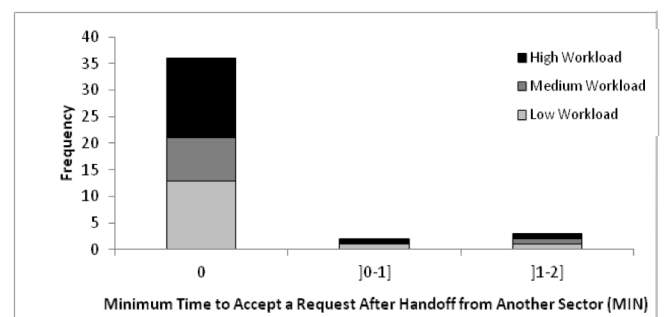


Figure 22 Distribution of acceptable request time after handoff.

G. Request with Additional Waypoints

Controllers were asked how many additional waypoints in a trajectory change request they would accept. The acceptable number ranged between a maximum of twenty waypoints under low workload and zero under high workload situations. The downward trend in the mean acceptable number of additional waypoints and its standard deviation with the workload level can be seen in Figure 23. The mean ranged between 7.5 waypoints under low workload and 2.5 under high workload. Similar trend is seen in the distribution shown in Figure 24. Most controllers would accept only 2 additional waypoints under high workload as shown by the mode of the frequency plot in Figure 24. Under low workload most would accept four to five additional waypoints. Controllers also replied that the number of acceptable waypoints to be added to a route depends on their familiarity with the waypoints. It is easier for them to add familiar waypoints to the route.

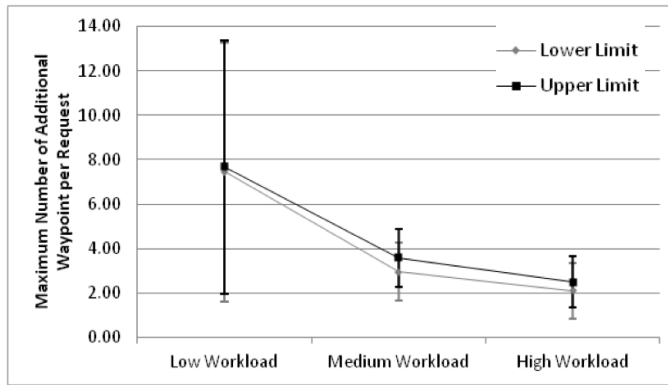


Figure 23 Maximum number of additional waypoint per request.

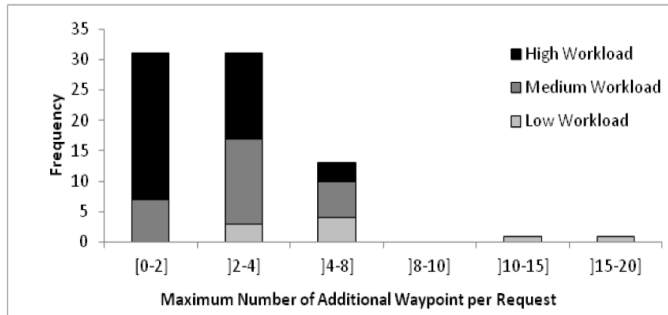


Figure 24 Distribution of acceptable number of additional waypoints.

H. Request with Lateral and Vertical Maneuvers

Controllers were asked if a trajectory change request that includes lateral and vertical components is acceptable under different workload conditions. Most controllers answered that the combination of lateral and vertical does not constitute a problem. Sometimes moving to a different altitude could be even advantageous for their workload. Some controllers replied that it can become an issue only if the altitude of the request puts the aircraft in a different stratum of airspace. In that case, they have to hand the aircraft off to another sector, either above or below them, adding to their workload. A few controllers

answered that they might accommodate first one dimension of the request, for example the vertical, and then the lateral part.

I. Request with Unfamiliar Waypoints

Controllers were asked if a trajectory change request that includes E-Class (low altitude) waypoints is acceptable when flying in class A airspace (en-route) under different workload conditions. Almost all controllers answered that as long as the waypoint's name is in the system it is not a problem which airspace class it belongs to. Some controllers replied that the familiarity with the waypoints can be an issue. If a request includes a waypoint that they are not familiar with, their workload increases because they need to search for the waypoint's location to assess the impact of the trajectory change. This was also corroborated during the observations.

V. SUMMARY AND CONCLUSIONS

All of the controllers interviewed showed an enthusiastic reaction to the potential of pilots being aware of the sector boundaries and accounting for them in making their requests. The following is a summary of the corresponding recommendations for TAP trajectory change advisories, based on the analysis of each of the factors in the previous section:

Request interaction with active SUA: It is recommended that trajectory change requests maintain the minimum separation of three nautical miles from an active SUA at all times. It is also recommended that if the pilot is aware of the controller workload level, the trajectory change request maintains about five nautical miles distance from the active SUA during high workload. It should also be noted that some experienced controllers in ZJX commented that they would negotiate with the military authority to allow a trajectory change request to penetrate into an active SUA if the activity in the SUA was low and if there was an operational need such as in the presence of weather. Therefore, closer distances to an active SUA can be entertained if needed.

Request flying along sector boundaries: it is recommended that a trajectory change request avoids a point out under high workload situations. This can be achieved by ensuring the required 2.5 nautical miles from sector boundaries.

Request sector intrusion: It is recommended that a trajectory change request avoids an intrusion point-out situation under high workload situations. This can be achieved by ensuring the required 2.5 nautical miles from the boundary between two sectors. However, based on the controllers' answers, it is expected that sector clipping is more acceptable than flying along sector boundaries.

Request time before handoff to another sector or center: It is recommended to avoid making a trajectory change request when the aircraft is being handed off to the next sector or center at least under high workload situations. A request desired time before handoff may range between two minutes under low workload to five minutes under high workload,

prior to the threshold of three nautical miles before the sector boundary that is used by the automation to initiate a handoff.

Request time after handoff from another sector: It is recommended that no delay factor be introduced to making a trajectory change request after handoff to a sector, because the controllers would like to hear the request as early as possible.

Request with multiple waypoints: It is recommended that only two additional waypoints be requested under high workload situations. If the waypoints are not familiar, the number should also be limited to five or seven.

Request with multiple maneuvers: It is recommended that lateral and vertical maneuvers can be combined in trajectory change requests. Particular attention may be given to making altitude change requests that change the airspace stratum.

Request with unfamiliar waypoint: It is recommended that no constraint on the waypoints' airspace class be added when calculating trajectory change requests. In addition, if it is possible to distinguish familiar from unfamiliar waypoints, preference may be given to the ones that the controllers are familiar with. On the other hand, no problem is anticipated if the automation finds a benefit of using an unfamiliar waypoint as long as it is in the data base used by the controllers.

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